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(54) Coated cutting tool

(57) A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate and hard coating layers including an aluminum oxide-based layer essentially consisting of aluminum oxide, the hard coating layers having an average thickness of 3 to 20 μm and being formed on the tungsten carbide substrate by chemical and/or physical vapor deposition; the aluminum oxide-based layer containing 0.005 to 0.5 percent by weight of chlorine.

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a cutting tool whose cutting member made of a coated carbide alloy (hereinafter referred to as "coated carbide cutting member") in which a thick, uniform Al_2O_3-based layer essentially consisting of aluminum oxide (hereinafter Al_2O_3) is formed as a hard coating layer. The cutting member exhibits no chipping in continuous and interrupted cutting of, for example, steel or cast iron and exhibits stable cutting ability for long periods. Inventors use the term "cutting member" as those which have a function to actually cut off the metal work piece, mainly like exchangeable cutting insert to be mounted on face milling cutter body, bit shank of turning tool, and cutting blade of end mill.

2. Description of the Related Art

Coated carbide cutting members have been known in which the cutting members comprise a tungsten carbide substrate (hereinafter carbide substrate) and hard coating layers comprising an Al_2O_3 layer and at least one layer, for example, selected from the group consisting of a titanium carbide (TiC) layer, a titanium nitride (TiN) layer, a titanium carbonitride (TiCN) layer, a titanium oxide (TiO_2) layer, a titanium carboxide (TiCO) layer, a titanium nitroxide (TiNO) layer, and a titanium carbonitroxide (TiCNO) layer and the hard coating layer is formed by chemical and/or physical vapor deposition and has an average thickness of 3 to 20 μm.

Further, it has been known that the Al_2O_3 layer composing the hard coating layer is formed from a reactive gas comprising

1 to 20 percent by volume of aluminum trichloride ($AlCl_3$),
0.5 to 30 percent by volume of carbon dioxide (CO_2),
1 to 30 percent by volume of carbon monoxide (CO) or hydrogen chloride (HCl) if necessary, and
the balance being hydrogen,

at a reaction temperature of 950 to 1,100 °C and an ambient pressure of 20 to 200 torr.

Recently, highly durable coated carbide cutting members have been in demand with the promotion of factory automation and labor saving in cutting. Among hard coating layers, thickening of the Al_2O_3 layer exhibits excellent resistance against oxidation, thermal stability and high hardness, and has been investigated in response to such demands. However, it is inevitable that the Al_2O_3 layer creates local nonuniformities in conventional deposition processes for thickening, and the resulting cutting members have significant nonuniformity in thickness between the flank, rake and edge (the cross of the flank and the rake). When such cutting members are used for interrupted cutting of steel and cast iron, cutting tool chipping easily forms, resulting in a relatively short duration.

SUMMARY OF THE INVENTION

The present inventors have investigated the improvement in resistance against chipping of a deposited Al_2O_3 layer composing a hard coating layer of a coated carbide cutting member. As a result, it has been found that a deposited Al_2O_3 layer (hereinafter Al_2O_3-based layer) which is formed by the following process exhibits excellent resistance against oxidation and thermal stability and high hardness: The Al_2O_3-based layer is formed by CVD or plasma CVD using a reactive gas containing 1 to 10 percent by volume (hereinafter merely percent) of $AlCl_3$, 1 to 5 percent of hydrogen (H_2), 5 to 15 percent of nitrogen oxide (NO_x) and 0.05 to 0.7 percent of titanium tetrachloride ($TiCl_4$) in an inert carrier gas at a temperature of 850 to 1,150 °C and a pressure of 20 to 200 torr. The resulting layer contains chlorine. The crystals in the layer are fined by controlling the chlorine content from 0.005 to 0.5 percent by weight (hereinafter merely percent). Further, local fluctuation in the thickness caused by thickening of the layer can be significantly reduced by controlling the composition of the reactive gas and the ambience so that the Ti content is 1.5 to 15 percent and the Cl content is 0.05 to 0.5 percent in the layer, thus the resulting cutting member has excellent uniformity in thicknesses between the flank, rake and edge (the cross of the flank and the rake). Moreover, coarsening of crystal grains in the thick layer can be reduced by controlling the Zr and/or Hf contents from 0.5 to 10 percent. A coated carbide cutting member comprising a hard coating layer including the Al_2O_3-based layer is durable to long-term continuous and interrupted cutting of steel and cast iron without chipping of the cutting member.

In accordance with the present invention, a coated carbide alloy cutting member exhibiting excellent resistance against chipping comprises: a tungsten carbide substrate and hard coating layers including an aluminum oxide-based layer essentially consisting of aluminum oxide having an average thickness of 3 to 20 μm and formed on the tungsten

carbide substrate by chemical and/or physical vapor deposition; wherein the aluminum oxide-based layer contains 0.005 to 0.5 percent by weight of chlorine. The improvement in resistance against chipping may be due to fining of crystal grains in the deposited layer.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the present invention, the Cl content of the Al_2O_3-based layer composing the hard coating layer of the coated carbide cutting member is determined to be 0.005 to 0.5 percent by weight (hereinafter merely percent). When the Cl content is less than 0.005 percent, the advantages set forth above cannot be achieved. On the other hand, a Cl content of over 0.5 percent loses characteristics, in particular wear resistance inherent to the Al_2O_3-based layer.

A layer having a uniform thickness can be formed in the presence of both Ti and Cl components. Satisfactory results cannot be achieved if the Ti content is less than 1.5 percent or the Cl content is less than 0.005 percent. On the other hand, excellent characteristics inherent to the Al_2O_3-based layer deteriorate if the Ti content exceeds 15 percent or the Cl content exceeds 0.5 percent. Thus, the Ti content is set from 1.5 to 15 percent and the Cl content is set from 0.005 to 0.5 percent.

Coarsening of crystal grains decreases the excellent characteristics of the Al_2O_3-based layer, but this can be reduced with Zr and/or Hf, particularly in the case of thicker layers. Satisfactory results cannot be achieved if the content is less than 0.5 percent. On the other hand, excellent characteristics inherent to the Al_2O_3-based layer deteriorate if the content exceeds 10 percent. Thus, the Zr and/or Hf content is set from 0.5 to 10 percent.

It is preferable that the total content of Ti, Cl, Zr and Hf in the Al_2O_3-based layer be controlled to be within 17.5 percent by weight, because the wear resistance significantly decreases if the total content exceeds the upper limit set forth above.

The average thickness of the hard coating layer is set to be 3 to 20 μm. Excellent wear resistance cannot be achieved at a thickness of less than 3 μm, whereas damage and chipping of the cutting member easily occur at a thickness of over 20 μm.

EXAMPLES

The coated carbide cutting member in accordance with the present invention will now be illustrated in detail with reference to the following EXAMPLES.

EXAMPLE 1

The following powders were prepared as raw materials: a WC powder with an average grain size of 2.8 μm; a coarse WC powder with an average grain size of 4.9 μm; a TiC/WC powder with an average grain size of 1.5 μm (TiC/WC = 30/70 by weight); a (Ti,W)CN powder with an average grain size of 1.2 μm (TiC/TiN/WC = 24/20/56); a TaC/NbC powder with an average grain size of 1.2 μm (TaC/NbC = 90/10); and a Co powder with an average grain size of 1.1 μm. These powders were compounded based on the formulation shown in Table 1, wet-mixed in a ball mill for 72 hours, and dried. The dry mixture was pressed to form a green compact for cutting insert defined in ISO-CNMG120408 (for carbide substrates A through D) or ISO-SEEN42AFTN1 (for carbide substrate E), followed by vacuum sintering under the conditions set forth in Table 1. Carbide substrates A through E were prepared in such a manner.

The carbide substrate B was held in a CH_4 atmosphere of 100 torr at 1400 °C for 1 hour, followed by annealing for carburization. The carburized substrate was subjected to treatment by acid and barrel finishing to remove carbon and cobalt on the substrate surface. The substrate was covered with a Co-enriched zone having a thickness of 42 μm and a maximum Co content of 15.9 percent by weight at a depth 11 μm from the surface of the substrate.

Sintered carbide substrates A and D have a Co-enriched zone having a thickness of 23 μm and a maximum Co content of 9.1 percent by weight at a depth 17 μm from the surface of the substrate. Carbide substrates C and E have no Co-enriched zone and have homogeneous microstructures.

The Rockwell hardness (Scale A) of each of the carbide substrates A through E are shown in Table 1.

The surfaces of the carbide substrates A through E were subjected to honing and chemical vapor deposition using conventional equipment under the conditions shown in Tables 2 or 3 to form hard coating layers having a composition and a designed thickness (at the flank of the cutting insert), wherein l-TiCN in Table 2 represents TiCN having a crystal structure longitudinally grown described in Japanese Unexamined Patent Publication No. 6-8010, p-TiCN in the same table represents TiCN having a general crystal grain structure, each Al_2O_3 (a) through (e) in Table 3 represents an Al_2O_3-based layer, and Al_2O_3 (f) represents an Al_2O_3 layer (the same as in Tables 4 and 5). Coated carbide cutting inserts in accordance with the present invention 1 through 10 and conventional coated carbide cutting inserts 1 through 10 were produced in such a manner.

The resulting coated carbide cutting inserts were subjected to measurement of the maximum thickness of the cutting edge, at which the flank and the rake cross each other, of the Al_2O_3-based layer and the Al_2O_3 layer (in Tables 6

and 7, both are referred to as merely Al_2O_3 layer) as the hard coating layer. Further, the thicknesses of those layers at the flank and rake at positions 1 mm from the cutting edge were measured. These results are shown in Tables 6 and 7.

In the hard coated layer, the thicknesses of layers other than both the Al2O3 layer and the Al2O3-based layer do not have substantial local fluctuations and are identical to the designed thicknesses.

The Al_2O_3-based layer of the cutting insert in accordance with the present invention or the conventional Al_2O_3 layer was subjected to elemental analysis using an EPMA (electron probe micro analyzer). When the top surface is a TiN layer, the TiN layer was removed with aqueous hydrogen peroxide before the analysis. The cutting inserts used for elemental analysis are identical to the ones used in the cutting test. The elemental analysis was carried out by irradiating an electron beam having a diameter of 1 mm onto the center of the flank for cutting inserts having a shape defined in ISO-CNMG120408 or onto the center of the rake for cutting inserts having a shape defined in ISO-SEEN42AFTN1.

As a result, the Al_2O_3-based layers of the coated carbide cutting inserts in accordance with the present invention contain 52.8 to 53.1 percent by weight of Al, and 46.5 to 46.9 percent by weight of O, 0.014 to 0.38 percent by weight of Cl, whereas conventional Al_2O_3 layers contain 52.8 to 53.0 percent by weight of Al and 47.0 to 47.2 percent by weight of O, and Cl was not detected.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 1 and 2 and conventional coated carbide cutting inserts 1 and 2 were evaluated by dry continuous and interrupted cutting tests as follows:

<u>Conditions for dry continuous cutting test of ductile cast iron</u>

Material to be cut: round bar based on JIS-FCD450
Cutting speed: 200 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 20 minutes

<u>Conditions for dry interrupted cutting test of ductile cast iron</u>

Material to be cut: round bar based on JIS-FCD450 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.25 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 3 and 4 and conventional coated carbide cutting inserts 3 and 4 were evaluated by dry continuous and interrupted cutting tests as follows:

<u>Conditions for dry continuous cutting test of alloy steel</u>

Material to be cut: round bar based on JIS-SNCM439
Cutting speed: 200 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 20 minutes

<u>Conditions for dry interrupted cutting test of alloy steel</u>

Material to be cut: round bar based on JIS-SNCM439 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.25 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 5 and 6 and conventional coated carbide cutting inserts 5 and 6 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of carbon steel

Material to be cut: round bar based on JIS-S45C
Cutting speed: 200 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 20 minutes

Conditions for dry interrupted cutting test of carbon steel

Material to be cut: round bar based on JIS-S45C with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.25 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 6 and 8 and conventional coated carbide cutting inserts 7 and 8 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of cast iron

Material to be cut: round bar based on JIS-FC300
Cutting speed: 250 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 20 minutes

Conditions for dry interrupted cutting test of cast iron

Material to be cut: round bar based on JIS-FC300 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.25 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 9 and 10 and conventional coated carbide cutting inserts 9 and 10 were evaluated by a dry milling test as follows:

Conditions for dry milling test of alloy steel

Material to be cut: square bar of 100-mm wide and 500-mm long based on JIS-SCM440
Cutting tool configuration: single cutting insert mounted with a cutter of 125-mm diameter
Rotation: 510 r.p.m.
Cutting speed: 200 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.2 mm/tooth
Cutting time: 3 passes (5.3 minutes per pass)

The resistances against chipping in this test were evaluated by flank wear.

These results are shown in Tables 6 and 7.

EXAMPLE 2

The same carbide substrates A through E as EXAMPLE 1 were prepared. The surfaces of the carbide substrates A through E were subjected to honing and chemical vapor deposition using conventional equipment under the conditions shown in Tables 2 or 8 to form hard coating layers having a composition and a designed thickness (at the flank of

the cutting insert), wherein each Al_2O_3 (a) through (h) in Table 8 represents an Al_2O_3-based layer, and Al_2O_3 (i) represents an Al_2O_3 layer (the same as in Tables 9 and 10). Coated carbide cutting inserts in accordance with the present invention 11 through 27 and conventional coated carbide cutting inserts 11 through 20 were produced in such a manner.

The resulting coated carbide cutting inserts were subjected to measurement of the maximum thickness of the cutting edge, at which the flank and the rake cross each other, of the Al_2O_3-based layer and the Al_2O_3 layer (in Tables 11 and 12, both are referred to as merely Al_2O_3 layer) as the hard coating layer. Further, the thicknesses of these layers at the flank and rake at positions 1 mm from the cutting edge were measured. These results are shown in Tables 11 and 12.

In the hard coated layer, the thicknesses of layers other than both the Al2O3 layer and the Al2O3-based layer do not have substantial local fluctuations and are identical to the designed thicknesses.

The Al_2O_3-based layer of the cutting insert in accordance with the present invention or the conventional Al_2O_3 layer was subjected to elemental analysis using an EPMA (electron probe micro analyzer). Elemental analysis was carried out based on the same procedure as Example 1.

As a result, the Al_2O_3-based layers of the coated carbide cutting inserts in accordance with the present invention contain 39.9 to 51.9 percent by weight of Al, 46.0 to 46.4 percent by weight of O, 2.1 to 12.9 percent by weight of Ti, and 0.011 to 0.18 percent by weight of Cl, whereas conventional Al_2O_3 layers contain 52.8 to 53.0 percent by weight of Al and 47.0 to 47.2 percent by weight of O, and Ti and Cl were not detected.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 11 through 18 and conventional coated carbide cutting inserts 11 through 14 were evaluated by dry continuous and interrupted cutting tests as follows:

<u>Conditions for dry continuous cutting test of alloy steel</u>

Material to be cut: round bar based on JIS-SCM440
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

<u>Conditions for dry interrupted cutting test of alloy steel</u>

Material to be cut: round bar based on JIS-SCM440 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 19 through 23 and conventional coated carbide cutting inserts 15 and 16 were evaluated by dry continuous and interrupted cutting tests as follows:

<u>Conditions for dry continuous cutting test of ductile cast iron</u>

Material to be cut: round bar based on FCD450
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

<u>Conditions for dry interrupted cutting test of ductile cast iron</u>

Material to be cut: round bar based on FCD450 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting insert in accordance with the present invention 24 and conventional coated carbide cutting insert 17 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of alloy steel

Material to be cut: round bar based on JIS-SNCM439
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of alloy steel

Material to be cut: round bar based on JIS-SNCM439 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting insert in accordance with the present invention 25 and conventional coated carbide cutting insert 18 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of carbon steel

Material to be cut: round bar based on JIS-S45C
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of carbon steel

Material to be cut: round bar based on JIS-S45C with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting insert in accordance with the present invention 26 and conventional coated carbide cutting insert 19 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of cast iron

Material to be cut: round bar based on JIS-FC300
Cutting speed: 350 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of cast iron

Material to be cut: round bar based on JIS-FC300 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting insert in accordance with the present invention 27 and conventional coated carbide cutting insert 20 were evaluated by a dry milling test as follows:

Conditions for dry milling test of alloy steel

Material to be cut: square bar of 100-mm wide and 500-mm long based on JIS-SCM440
Cutting tool configuration: single cutting insert mounted with a cutter of 125-mm diameter
Rotation: 510 r.p.m.
Cutting speed: 200 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.2 mm/tooth
Cutting time: 3 passes (5.3 minutes per pass)

The resistances against chipping in this test were evaluated by flank wear.

These results are shown in Tables 11 and 12.

EXAMPLE 3

The same carbide substrates A through E as EXAMPLE 1 were prepared. The surfaces of the carbide substrates A through E were subjected to honing and chemical vapor deposition using conventional equipment under the conditions shown in Tables 2 or 13 to form hard coating layers having a composition and a designed thickness (at the flank of the cutting insert), wherein each Al_2O_3 (a) through (i) in Table 13 represents an Al_2O_3-based layer, and Al_2O_3 (j) represents an Al_2O_3 layer (the same as in Tables 14 and 15). Coated carbide cutting inserts in accordance with the present invention 28 through 40 and conventional coated carbide cutting inserts 21 through 30 were produced in such a manner.

The resulting coated carbide cutting inserts were subjected to measurement of the maximum thickness of the cutting edge, at which the flank and the rake cross each other, of the Al_2O_3-based layer and the Al_2O_3 layer (in Tables 16 and 17, both are referred to as merely Al_2O_3 layer) as the hard coating layer. Further, the thicknesses of those layers at the flank and rake at positions 1 mm from the cutting edge were measured. These results are shown in Tables 16 and 17.

In the hard coated layer, the thicknesses of layers other than both the Al2O3 layer and the Al2O3-based layer do not have substantial local fluctuations and are identical to the designed thicknesses.

The Al_2O_3-based layer of the cutting insert in accordance with the present invention or the conventional Al_2O_3 layer was subjected to elemental analysis using an EPMA (electron probe micro analyzer). Elemental analysis was carried out by the same procedure as Example 1.

As a result, the Al_2O_3-based layers of the coated carbide cutting inserts in accordance with the present invention contain 41.1 to 52.1 percent by weight of Al, 46.3 to 46.2 percent by weight of O, 0.35 to 9.1 percent by weight of Zr, 0.42 to 10.4 percent by weight of Hf, and 0.014 to 0.15 percent by weight of Cl, whereas conventional Al_2O_3 layers contain 52.8 to 53.0 percent by weight of Al and 47.0 to 47.2 percent by weight of O, and Zr, Hf and Cl were not detected.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 28 through 32 and conventional coated carbide cutting inserts 21 and 22 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of ductile cast iron

Material to be cut: round bar based on JIS-FCD700
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of ductile cast iron

Material to be cut: round bar based on JIS-FCD700 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 33 and 34 and conventional coated carbide cutting inserts 23 and 24 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of alloy steel

Material to be cut: round bar based on JIS-SCM440
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of alloy steel

Material to be cut: round bar based on JIS-SCM440 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 35 and 36 and conventional coated carbide cutting inserts 25 and 26 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of carbon steel

Material to be cut: round bar based on JIS-S30C
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of carbon steel

Material to be cut: round bar based on JIS-S30C with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 37 and 38 and conventional coated carbide cutting inserts 27 and 28 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of cast iron

Material to be cut: round bar based on JIS-FC200
Cutting speed: 350 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of cast iron

Material to be cut: round bar based on JIS-FC200 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.

Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 39 and 40 and conventional coated carbide cutting inserts 29 and 30 were evaluated by a dry continual test as follows:

Conditions for dry milling test of alloy steel

Material to be cut: square bar of 100-mm wide and 500-mm long based on JIS-SCM440
Cutting tool configuration: single cutting insert mounted with a cutter of 125-mm diameter
Rotation: 510 r.p.m.
Cutting speed: 200 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.2 mm/tooth
Cutting time: 3 passes (5.3 minutes per pass)

The resistances against chipping in this test were evaluated by flank wear.

These results are shown in Tables 16 and 17.

EXAMPLE 4

The same carbide substrates A through E as EXAMPLE 1 were prepared. The surfaces of the carbide substrates A through E were subjected to honing and chemical vapor deposition using conventional equipment under the conditions shown in Tables 2 or 18 to form hard coating layers having a composition and a designed thickness (at the flank of the cutting insert), wherein l-TiCN in Table 2 represents TiCN having a crystal structure longitudinally grown described in Japanese Unexamined Patent Publication No. 6-8010, p-TiCN in the same table represents TiCN having a general crystal grain structure, each Al_2O_3 (a) through (k) in Table 18 represents an Al_2O_3-based layer, and Al_2O_3 (l) represents an Al_2O_3 layer (the same as in Tables 19 and 20). Coated carbide cutting inserts in accordance with the present invention 41 through 57 and conventional coated carbide cutting inserts 31 through 40 were produced in such a manner.

The resulting coated carbide cutting inserts were subjected to measurement of the maximum thickness of the cutting edge, at which the flank and the rake cross each other, of the Al_2O_3-based layer and the Al_2O_3 layer (in Tables 21 and 22, both are referred to as merely Al_2O_3 layer) as the hard coating layer. Further, the thicknesses of the flank and rake at positions 1 mm from the cutting edge were measured. These results are shown in Tables 21 and 22.

In the hard coated layer, the thicknesses of the Al2O3-based layer and layers other than the Al2O3 layer do not have substantial local fluctuations and are identical to the designed thicknesses.

The Al_2O_3-based layer of the cutting insert in accordance with the present invention or the conventional Al_2O_3 layer was subjected to elemental analysis using an EPMA (electron probe micro analyzer). Elemental analysis was carried out by the same procedure as Example 1.

As a result, the Al_2O_3-based layers of the coated carbide cutting inserts in accordance with the present invention contain 39.1 to 50.7 percent by weight of Al, 44.9 to 46.3 percent by weight of O, 1.9 to 13.6 percent by weight of Ti, 0.14 to 0.20 percent by weight of Cl, 0.3 to 8.5 percent by weight of Zr, and 0.3 to 9.6 percent by weight of Hf, whereas conventional Al_2O_3 layers contain 52.8 to 53.0 percent by weight of Al and 47.0 to 47.2 percent by weight of O, and Ti, Cl, Zr and Hf were not detected.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 41 through 49 and conventional coated carbide cutting inserts 31 and 36 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of ductile cast iron

Material to be cut: round bar based on JIS-FCD700
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of ductile cast iron

Material to be cut: round bar based on JIS-FCD700 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 50 and 51 and conventional coated carbide cutting insert 37 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of alloy steel

Material to be cut: round bar based on JIS-SCM439
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of alloy steel

Material to be cut: round bar based on JIS-SCM439 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 52 and 53 and conventional coated carbide cutting insert 38 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of carbon steel

Material to be cut: round bar based on JIS-S45C
Cutting speed: 300 m/min.
Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of carbon steel

Material to be cut: round bar based on JIS-S45C with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 54 and 55 and conventional coated carbide cutting insert 39 were evaluated by dry continuous and interrupted cutting tests as follows:

Conditions for dry continuous cutting test of cast iron

Material to be cut: round bar based on JIS-FC200
Cutting speed: 350 m/min.

Depth of cut: 1.5 mm
Feed rate: 0.3 mm/rev.
Cutting time: 15 minutes

Conditions for dry interrupted cutting test of cast iron

Material to be cut: round bar based on JIS-FC200 with four longitudinal grooves equally spaced
Cutting speed: 150 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.3 mm/rev.
Cutting time: 5 minutes

The resistances against chipping in both tests were evaluated by flank wear.

Resistances against chipping of coated carbide cutting inserts in accordance with the present invention 56 and 57 and conventional coated carbide cutting insert 40 were evaluated by a dry continual test as follows:

Conditions for dry milling test of alloy steel

Material to be cut: square bar of 100-mm wide and 500-mm long based on JIS-SCM440
Cutting tool configuration: single cutting insert mounted with a cutter of 125-mm diameter
Rotation: 510 r.p.m.
Cutting speed: 200 m/min.
Depth of cut: 2.0 mm
Feed rate: 0.2 mm/tooth
Cutting time: 3 passes (5.3 minutes per pass)

The resistances against chipping in this test were evaluated by flank wear.

These results are shown in Tables 21 and 22.

As set forth above, a coated carbide cutting member in accordance with the present invention has hard coating layers comprising an Al_2O_3-based layer in which Cl is included using a reactive gas diluted with an inert gas, and the Al_2O_3-based layer has a fine crystalline structure. In contrast, since a conventional coated carbide cutting member uses a hydrogen-base reactive gas to form the Al_2O_3 coating layer, the resulting Al_2O_3 layer has a coarse crystalline structure, and the thicknesses of the flank, rake and edge fluctuate significantly. Thus, the coated carbide cutting member in accordance with the present invention exhibits excellent wear resistance to continuous cutting of steel and cast iron and significantly excellent resistance against chipping to interrupted cutting, without the loosing excellent characteristics of the Al_2O_3 layer.

In particular, the local fluctuation of the thickness of the Al_2O_3-based layer is extremely low in the coated carbide cutting member in accordance with the present invention even when the Al_2O_3-based layer is thickened. Thus, the coated carbide cutting member exhibits significantly improved resistance against chipping to continuous and interrupted cutting of, for example, steel and cast iron, and exhibits excellent cutting characteristics for long terms. Such advantages contribute to factory automation and labor saving in relation to cutting operations.

Table 1

Carbide Substrate	Composition (weight %)					Vacuum Sintering Conditions			Rockwell Hardness (scale A) (HRA)
	Co	(Ti,W)C	(Ti,W)C N	(Ta,Nb) C	WC	Vacuum (torr)	Tempera-ture (°C)	Time (hr)	
A	6.3	-	6	4.1	Balance	0.10	1380	1	90.3
B	5.3	5.2	-	5.1	Balance	0.05	1450	1	90.9
C	9.5	8.1	-	4.9	Balance	0.05	1380	1.5	89.9
D	4.5	-	4.8	3.1	Balance	0.10	1410	1	91.4
E	10.2	-	-	2.2	Balance (Coarse)	0.05	1380	1	89.7

Table 2

Hard Coating Layer	Conditions for Forming Hard Coating Layer		
	Composition of Reactive Gas (Volume %)	Ambience	
		Pressure (torr)	Temperature (°C)
TiC	$TiCl_4$: 4.2%, CH_4: 4.5%, H_2: Balance	50	980
TiN (First layer)	$TiCl_4$: 4.2%, N_2: 25%, H_2: Balance	50	920
TiN (Other layer)	$TiCl_4$: 4.2%, N_2: 30%, H_2: Balance	200	1020
l-TiCN	$TiCl_4$: 4.2%, N_2: 20%, CH_3 CN: 0.6%, H_2: Balance	50	910
p-TiCN	$TiCl_4$: 4.2%, N_2: 20%, CH_4: 4%, H_2: Balance	50	1020
TiCO	$TiCl_4$: 2%, CO: 6%, H_2: Balance	50	980
TiNO	$TiCl_4$: 2%, NO: 6%, H_2: Balance	50	980
TiCNO	$TiCl_4$: 2%, CO: 3%, H_2: Balance	50	980
TiO_2	$TiCl_4$: 2%, CO_2: 8%, H_2: Balance	100	1000

Table 3

Hard Coating Layer		Conditions for Forming Al_2O_3 Layer		
Kind	Designed Cl Content (weight %)	Composition of Reactive Gas (Volume %)	Ambience	
			Pressure (torr)	Temperature (°C)
Al_2O_3(a)	Cl:0.005%	$AlCl_3$:5.0%, NO:15.0%, H_2:5.0%, Ar:Balance	50	1050
Al_2O_3(b)	Cl:0.01%	$AlCl_3$:5.0%, NO:15.0%, H_2:3.0%, Ar:Balance	50	1050
Al_2O_3(c)	Cl:0.05%	$AlCl_3$:5.0%, NO:10.0%, H_2:3.0%, Ar:Balance	50	1000
Al_2O_3(d)	Cl:0.1%	$AlCl_3$:5.0%, NO:5.0%, H_2:3.0%, Ar:Balance	50	950
Al_2O_3(e)	Cl:0.3%	$AlCl_3$:5.0%, NO:5.0%, H_2:1.0%, Ar:Balance	50	950
Al_2O_3(f)	-	$AlCl_3$:4.0%, CO_2:12.0%, H_2:Balance	50	1000

Table 4

Insert		Substrate	Hard Coating Layer (Figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
This Invention	1	A	TiN (0.3)	l-TiCN (5)	TiCO (0.3)	Al_2O_3 (a) (5)	TiN (0.3)	
	2	A	TiN (0.3)	l-TiCN (5)	TiCO (0.3)	Al_2O_3 (b) (8)	TiN (0.3)	
	3	B	TiC (6)	TiCO (0.3)	Al_2O_3 (c) (6)			
	4	B	TiC (6)	TiCO (0.3)	Al_2O_3 (c) (6)	TiN (0.3)		
	5	C	p-TiCN (6)	TiCO (0.3)	Al_2O_3 (c) (3)	TiN (0.3)		
	6	C	p-TiCN (6)	TiCO (0.3)	Al_2O_3 (c) (6)	TiN (0.3)		
	7	D	TiN (0.3)	l-TiCN (5)	TiCO (0.3)	Al_2O_3 (c) (6)	TiN (0.3)	
	8	D	TiN (0.3)	l-TiCN (5)	TiO_2 (0.3)	Al_2O_3 (c) (10)		
	9	E	TiC (2)	TiCNO (0.3)	Al_2O_3 (d) (1.0)	TiN (0.3)		
	10	E	p-TiCN (2)	TiNO (0.3)	Al_2O_3 (e) (2.0)	TiN (0.3)		

Table 5

Insert		Substrate	Hard Coating Layer (Figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
Conventional	1	A	TiN (0.3)	l-TiCN (5)	TiCO (0.3)	Al_2O_3 (f) (5)	TiN (0.3)	
	2	A	TiN (0.3)	l-TiCN (5)	TiCO (0.3)	Al_2O_3 (f) (8)	TiN (0.3)	
	3	B	TiC (6)	TiCO (0.3)	Al_2O_3 (f) (6)			
	4	B	TiC (6)	TiCO (0.3)	Al_2O_3 (f) (6)	TiN (0.3)		
	5	C	p-TiCN (6)	TiCO (0.3)	Al_2O_3 (f) (3)	TiN (0.3)		
	6	C	p-TiCN (6)	TiCO (0.3)	Al_2O_3 (f) (6)	TiN (0.3)		
	7	D	TiN (0.3)	l-TiCN (5)	TiCO (0.3)	Al_2O_3 (f) (6)	TiN (0.3)	
	8	D	TiN (0.3)	l-TiCN (5)	TiO_2 (0.3)	Al_2O_3 (f) (10)		
	9	E	TiC (2)	TiCNO (0.3)	Al_2O_3 (f) (1.0)	TiN (0.3)		
	10	E	p-TiCN (2)	TiNO (0.3)	Al_2O_3 (f) (2.0)	TiN (0.3)		

Table 6

Insert		Thickness of Al_2O_3 Layer (μm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
This Invention	1	5.0	5.5	4.8	0.25	0.26
	2	8.1	9.2	7.6	0.29	0.22
	3	6.0	6.8	6.0	0.27	0.23
	4	6.2	7.0	5.7	0.25	0.21
	5	2.9	3.3	2.7	0.26	0.31
	6	6.0	6.8	5.6	0.33	0.27
	7	6.0	6.8	5.5	0.31	0.30
	8	9.8	11.2	9.3	0.29	0.21
	9	1.0	1.1	0.9	-	0.22
	10	2.0	2.1	1.9	-	0.29

Table 7

Insert		Thickness of Al_2O_3 Layer (μm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
Conventional	1	4.8	8.2	2.1	0.31	Failure at 4.5 minutes
	2	7.8	14.0	3.1	0.34	Failure at 2.0 minutes
	3	5.9	9.8	2.6	0.33	Failure at 1.5 minutes
	4	6.0	9.2	3.4	0.38	Failure at 2.5 minutes
	5	3.0	4.6	1.8	0.39	Failure at 2.5 minutes
	6	5.8	9.1	3.0	0.49	Failure at 3.0 minutes
	7	6.0	10.2	2.4	0.31	Failure at 2.0 minutes
	8	9.9	17.1	4.6	0.44	Failure at 2.0 minutes
	9	1.0	1.5	0.6	-	Failure at 4.5 minutes
	10	2.0	3.4	1.2	-	Failure at 2.5 minutes
Remark: Failure is caused by chipping.						

Table 8

Hard Coating Layer		Conditions for Forming Hard Coating Layer		
Kind	Designed Ti and Cl Content (weight %)	Composition of Reactive Gas (Volume %)	Ambience	
			Pressure (torr)	Temperature (°C)
Al_2O_3(a)	Ti:1.5%, Cl:0.07%	NO:12.3%, H_2:2.5%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	20	950
Al_2O_3(b)	Ti:5%, Cl:0.07%	NO:12.3%, H_2:2.5%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	50	950
Al_2O_3(c)	Ti:10%, Cl:0.07%	NO:12.3%, H_2:2.5%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	200	950
Al_2O_3(d)	Ti:15%, Cl:0.07%	NO:12.3%, H_2:4.0%, $AlCl_3$:5.7%, $TiCl_4$:0.7%, Ar:Balance	50	950
Al_2O_3(e)	Ti:5%, Cl:0.005%	NO:12.3%, H_2:3.0%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	50	950
Al_2O_3(f)	Ti:5%, Cl:0.1%	NO:12.3%, H_2:2.0%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	50	950
Al_2O_3(g)	Ti:10%, Cl:0.005%	NO:12.3%, H_2:2.5%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	50	900
Al_2O_3(h)	Ti:2.5%, Cl:0.1%	NO:12.3%, H_2:2.5%, $AlCl_3$:5.7%, $TiCl_4$:0.33%, Ar:Balance	50	1050
Al_2O_3(i)	-	CO_2:6.5%, $AlCl_3$:2%, H_2:Balance	50	980

Table 9

Insert		Subst-rate	Hard Coating Layer (Figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
This Invention	11	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (a) (6)	TiN (0.1)	-
	12	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (6)	TiN (0.1)	-
	13	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (10)	TiN (0.1)	-
	14	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (4)	TiN (0.1)	-
	15	A	TiN (0.1)	p-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (6)	TiN (0.1)	-
	16	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (6)	-	-
	17	A	TiC (1)	p-TiCN (2)	TiC (5)	TiCNO (0.1)	Al_2O_3 (b) (6)	TiN (0.1)
	18	A	TiN (0.1)	1-TiCN (5)	TiC (3)	Al_2O_3 (b) (6)	TiN (0.1)	-
	19	A	TiN (0.1)	1-TiCN (5)	TiC (3)	TiNO (0.1)	Al_2O_3 (b) (6)	TiN (0.1)
	20	A	TiN (0.1)	1-TiCN (5)	TiC (3)	TiCO (0.1)	Al_2O_3 (b) (6)	TiN (0.1)
	21	A	TiN (0.1)	1-TiCN (5)	TiC (3)	TiO_2 (0.1)	Al_2O_3 (b) (6)	TiN (0.1)
	22	A	TiN (0.1)	1-TiCN (7)	TiNO (0.1)	Al_2O_3 (c) (6)	TiN (0.1)	-
	23	A	TiN (0.1)	1-TiCN (7)	TiNO (0.1)	Al_2O_3 (d) (6)	TiN (0.1)	-
	24	B	TiN (0.1)	1-TiCN (7)	TiCO (0.1)	Al_2O_3 (e) (6)	TiN (0.1)	-

Continued to Table 10

Table 10

Insert		Substrate	Hard Coating Layer (figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
This Inveniton	25	C	TiN (0.1)	1-TiCN (2)	TiCO (0.1)	Al_2O_3 (f) (3)	TiN (0.1)	-
	26	D	TiN (0.1)	1-TiCN (7)	TiO_2 (0.1)	Al_2O_3 (g) (6)	TiN (0.1)	-
	27	E	TiN (0.1)	1-TiCN (0.5)	TiO_2 (0.1)	Al_2O_3 (h) (2.5)	TiN (0.1)	-
Conventional	11	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (i) (6)	TiN (0.1)	-
	12	A	TiN (0.1)	1-TiN (7)	TiCNO (0.1)	Al_2O_3 (i) (10)	TiN (0.1)	-
	13	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (i) (4)	TiN (0.1)	-
	14	A	TiN (0.1)	p-TiN (7)	TiCNO (0.1)	Al_2O_3 (i) (6)	TiN (0.1)	-
	15	A	TiC (1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (i) (6)	-	-
	16	A	TiN (0.1)	1-TiCN (2)	TiC (3)	TiCNO (0.1)	Al_2O_3 (i) (6)	TiN (0.1)
	17	B	TiN (0.1)	1-TiCN (5)	TiC (3)	Al_2O_3 (i) (6)	TiN (0.1)	-
	18	C	TiN (0.1)	1-TiCN (2)	TiNO (0.1)	Al_2O_3 (i) (3)	TiN (0.1)	-
	19	D	TiN (0.1)	1-TiCN (5)	TiC (3)	TiCO (0.1)	Al_2O_3 (i) (6)	TiN (0.1)
	20	E	TiN (0.1)	1-TiCN (0.5)	TiO_2 (0.1)	Al_2O_3 (i) (2.5)	TiN (0.1)	-

Table 11

Insert		Thickness of Al_2O_3 Layer (µm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
This Invention	11	6.2	8.3	5.8	0.19	0.23
	12	6.2	8.3	6.0	0.16	0.20
	13	10.3	13.2	9.9	0.16	0.21
	14	3.9	5.2	4.0	0.17	0.20
	15	6.1	8.2	6.0	0.18	0.20
	16	6.0	8.3	5.9	0.17	0.22
	17	6.2	8.3	5.9	0.18	0.21
	18	6.2	8.2	6.0	0.17	0.23
	19	6.0	8.2	5.9	0.20	0.23
	20	6.1	8.3	6.0	0.20	0.23
	21	6.0	8.2	5.9	0.19	0.26
	22	6.2	8.2	6.1	0.23	0.27
	23	6.1	8.3	6.2	0.24	0.26
	24	6.0	7.9	6.0	0.19	0.27
Remark: Failure is caused by chipping.						

Table 12

Insert		Thickness of Al_2O_3 Layer (µm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
This Invention	25	3.1	3.9	2.9	0.21	0.23
	26	6.2	8.0	6.1	0.24	0.30
	27	2.5	3.3	2.2	-	0.24
Conventional Method	11	6.1	11.2	3.0	0.20	Failure at 4.0 minutes
	12	10.2	18.5	5.0	0.20	Failure at 4.0 minutes
	13	4.0	7.5	2.1	0.21	Failure at 4.0 minutes
	14	6.0	11.0	2.9	0.21	Failure at 4.5 minutes
	15	5.9	10.8	3.0	0.28	Failure at 3.5 minutes
	16	6.1	11.3	3.2	0.27	Failure at 3.0 minutes
	17	6.0	11.2	3.0	0.20	Failure at 2.5 minutes
	18	3.0	5.2	1.4	0.25	Failure at 3.5 minutes
	19	5.9	11.0	3.0	0.31	Failure at 2.5 minutes
	20	2.5	4.3	1.4	-	Failure at 3.5 minutes
Remark: Failure is caused by chipping.						

Table 13

Hard Coating Layer				Conditions for Forming Hard Coating Layer							
Kind	Designed Content (weight %)			Composition of Reactive Gas (Volume %)						Ambience	
	Zr	Hf	Cl	$AlCl_3$	NO	$ZrCl_4$	$HfCl_4$	H_2	Ar	Pressure (torr)	Temperature (°C)
Al_2O_3(a)	0.2	0.3	0.03	3	10	0.04	0.06	3	Balance	50	950
Al_2O_3 (b)	1.5	1.5	0.03	3	10	0.1	0.1	3	Balance	50	950
Al_2O_3(c)	5	5	0.03	3	10	0.3	0.3	3	Balance	50	950
Al_2O_3(d)	1.5	1.5	0.005	3	10	0.1	0.1	5	Balance	50	1000
Al_2O_3(e)	1.5	1.5	0.1	3	10	0.1	0.1	1	Balance	50	900
Al_2O_3(f)	0.5	-	0.01	4	8	0.1	-	4	Balance	50	950
Al_2O_3(g)	10	-	0.01	4	8	0.6	-	4	Balance	50	950
Al_2O_3(h)	-	0.5	0.05	5	12	-	0.1	2	Balance	50	950
Al_2O_3(i)	-	10	0.05	5	12	-	0.6	2	Balance	50	950
Al_2O_3(j)	-			CO_2: 6.5%, $AlCl_3$: 2%, H_2: Balance						50	980

Table 14

Insert		Subst-rate	Hard Coating Layer(figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
This Inveniton	28	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (a)(3)	TiN (0.1)	-
	29	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b)(5)	TiN (0.1)	-
	30	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b)(7)	TiN (0.1)	-
	31	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b)(9)	TiN (0.1)	-
	32	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b)(9)	-	-
	33	B	p-TiCN(6)	TiNO (0.1)	Al_2O_3 (b)(6)	TiO_2 (0.1)	TiN (0.1)	-
	34	B	TiC (7)	TiCO (0.1)	Al_2O_3 (c)(5)	-	-	-
	35	C	TiN (0.1)	l-TiCN (5)	TiC (3)	p-TiCN (0.1)	Al_2O_3 (d)(4)	TiN (0.1)
	36	C	p-TiCN (7)	Al_2O_3 (e)(6)	-	-	-	-
	37	D	TiN (0.3)	l-TiCN (6)	TiCNO (0.1)	Al_2O_3 (f)(7)	TiN (0.1)	-
	38	D	p-TiCN (6)	TiCNO (0.1)	Al_2O_3 (g) (7)	-	-	-
	39	E	TiC (0.5)	Al_2O_3 (h)(3)	-	-	-	-
	40	E	TiN (0.1)	l-TiCN (0.5)	TiNO (0.1)	Al_2O_3 (i) (2.5)	TiN (0.1)	-

Table 15

Insert		Sub-strate	Hard Coating Layer (figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
Conven-tional	21	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (j)(9)	TiN (0.1)	-
	22	A	TiN (0.1)	l-TiCN (7)	TiCNO (0.1)	Al_2O_3 (j)(9)	-	-
	23	B	p-TiCN (6)	TiNO (0.1)	Al_2O_3 (j)(6)	TiO_2 (0.1)	TiN (0.1)	-
	24	B	Tic (7)	TiCO (0.1)	Al_2O_3 (j) (5)	-	-	-
	25	C	TiN (0.1)	l-TiCN (5)	Tic (3)	p-TiCN (0.1)	Al_2O_3 (j)(4)	TiN (0.1)
	26	C	p-TiCN (7)	Al_2O_3 (j)(6)	-	-	-	-
	27	D	TiN (0.3)	l-TiCN (6)	TiCNO (0.1)	Al_2O_3 (j)(7)	TiN (0.1)	-
	28	D	p-TiCN (6)	TiCNO (0.1)	Al_2O_3 (j)(7)	-	-	-
	29	E	TiC (0.5)	Al_2O_3 (j)(3)	-	-	-	-
	30	E	TiN (0.1)	l-TiCN (0.5)	TiNO (0.1)	Al_2O_3 (j)(2.5)	TiN (0.1)	-

Table 16

Insert		Thickness of Al_2O_3 Layer (μm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
This Invention	28	3.0	3.7	2.9	0.20	0.25
	29	5.0	5.9	4.8	0.20	0.27
	30	7.1	8.2	6.7	0.19	0.26
	31	9.2	10.4	8.7	0.19	0.25
	32	9.0	10.5	8.6	0.18	0.29
	33	5.9	7.0	5.7	0.26	0.30
	34	5.0	6.0	4.8	0.23	0.31
	35	4.0	4.6	3.9	0.25	0.26
	36	6.0	7.0	5.8	0.27	0.22
	37	6.9	8.5	6.6	0.17	0.20
	38	7.0	8.3	6.9	0.17	0.24
	39	3.0	3.4	3.0	-	0.25
	40	2.5	2.9	2.4	-	0.24

Table 17

Insert		Thickness of Al_2O_3 Layer (µm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
Conventio nal	21	8.8	15.7	3.9	0.22	Failure at 3.5 minutes
	22	9.0	16.8	4.7	0.25	Failure at 3.0 minutes
	23	6.0	10.4	2.7	0.32	Failure at 3.0 minutes
	24	4.9	8.8	2.5	0.33	Failure at 3.5 minutes
	25	4.0	6.9	1.8	0.31	Failure at 4.5 minutes
	26	5.8	10.2	2.7	0.27	Failure at 4.0 minutes
	27	6.9	12.4	3.0	0.22	Failure at 4.0 minutes
	28	7.0	13.0	3.0	0.23	Failure at 3.5 minutes
	29	3.0	4.9	1.6	-	Failure at 5.5 minutes
	30	2.5	4.7	1.4	-	Failure at 6.5 minutes
Remark: Failure is caused by chipping.						

Table 18

Hard Coating Layer					Conditions for Forming Hard Coating Layer									
Kind	Designed Content (weight %)				Composition of Reactive Gas (Volume %)								Ambience	
	Ti	Cl	Zr	Hf	$AlCl_3$	NO	$TiCl_4$	$ZrCl_4$	$HfCl_4$	H_2	Ar	He	Temperature (°C)	Pressure (torr)
Al_2O_3 (a)	1.5	0.03	1.5	1.5	5	15	0.1	0.1	0.1	2.5	Balance	-	950	50
Al_2O_3 (b)	5	0.03	1.5	1.5	5	15	0.3	0.1	0.1	2.5	Balance	-	950	50
Al_2O_3 (c)	15	0.03	1.0	1.0	5	15	0.7	0.05	0.05	2.5	Balance	-	930	50
Al_2O_3 (d)	5	0.005	1.0	2.0	5	10	0.3	0.05	0.1	1	-	Balance	980	30
Al_2O_3 (e)	5	0.1	2.0	1.0	5	10	0.3	0.1	0.05	2.5	-	Balance	900	100
Al_2O_3 (f)	5	0.03	0.2	0.3	5	10	0.4	0.01	0.02	1	-	Balance	980	30
Al_2O_3 (g)	5	0.03	5	5	5	10	0.3	0.3	0.3	1	-	Balance	980	30
Al_2O_3 (h)	5	0.03	10	-	4	5	0.3	0.6	-	3.0	Balance	-	920	100
Al_2O_3 (i)	5	0.03	-	0.5	4	5	0.4	-	0.03	3.0	Balance	-	920	100
Al_2O_3 (j)	2	0.03	0.5	-	4	5	0.15	0.03	-	3.0	Balance	-	920	100
Al_2O_3 (k)	3	0.03	-	10	4	5	0.2	-	0.6	3.0	Balance	-	920	100
Al_2O_3 (l)	-				$AlCl_3$: 2.0%, CO_2: 6.5%, H_2: Balance								980	50

Table 19

Insert		Substrate	Hard Coating Layer (figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
This Invention	41	A	TiN (0.1)	1-TiCN (7)	TiCNO(0.1)	Al_2O_3 (a) (11)	TiN (0.1)	-
	42	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (9)	TiN (0.1)	-
	43	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (7)	TiN (0.1)	-
	44	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (5)	TiN (0.1)	-
	45	A	TiN (0.1)	p-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (3)	TiN (0.1)	-
	46	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (b) (3)	-	-
	47	A	TiC (1)	p-TiCN (2)	TiC (5)	TiCNO (0.1)	Al_2O_3 (b) (6)	TiN (0.1)
	48	A	TiN (0.1)	1-TiCN (5)	TiC (3)	Al_2O_3 (b) (6)	TiN (0.1)	-
	49	A	TiN (0.1)	1-TiCN (5)	TiC (3)	TiNO (0.1)	Al_2O_3 (c) (6)	TiN (0.1)
	50	B	TiN (0.1)	1-TiCN (3)	TiC (2)	TiCO (0.1)	Al_2O_3 (d) (8)	TiN (0.1)
	51	B	TiN (0.1)	1-TiCN (3)	TiC (2)	TiO_2 (0.1)	Al_2O_3 (e) (8)	TiN (0.1)
	52	C	TiN (0.1)	1-TiCN (5)	TiNO (0.1)	Al_2O_3 (f) (2)	TiN (0.1)	-
	53	C	TiN (0.1)	1-TiCN (5)	TiNO (0.1)	Al_2O_3 (g) (2)	TiN (0.1)	-
	54	D	TiN (0.1)	1-TiCN (3)	TiCO (0.1)	Al_2O_3 (h) (10)	TiN (0.1)	-

Table 20

Insert		Subst-rate	Hard Coating Layer (figure in parentheses means designed thickness)					
			First Layer	Second Layer	Third Layer	Fouth Layer	Fifth Layer	Sixth Layer
This Invention	55	D	TiN (0.1)	1-TiCN (3)	TiCO (0.1)	Al_2O_3 (i) (10)	TiN (0.1)	-
	56	E	TiN (0.1)	1-TiCN (0.5)	TiO_2 (0.1)	Al_2O_3 (j) (2.5)	-	-
	57	E	TiN (0.1)	1-TiCN (0.5)	TiO_2 (0.1)	Al_2O_3 (k) (2.5)	-	-
Conven-tional	31	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (1) (11)	TiN (0.1)	-
	32	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (1) (7)	TiN (0.1)	-
	33	A	TiN (0.1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (1) (5)	TiN (0.1)	-
	34	A	TiN (0.1)	p-TiCN (7)	TiCNO (0.1)	Al_2O_3 (1) (3)	TiN (0.1)	-
	35	A	TiC (1)	1-TiCN (7)	TiCNO (0.1)	Al_2O_3 (1) (6)	-	-
	36	A	TiN (0.1)	1-TiCN (2)	TiC (3)	TiCNO (0.1)	Al_2O_3 (1) (6)	TiN (0.1)
	37	B	TiN (0.1)	1-TiCN (3)	TiC (2)	TiO_2 (0.1)	Al_2O_3 (1) (8)	TiN (0.1)
	38	C	TiN (0.1)	1-TiCN (5)	TiNO (0.1)	Al_2O_3 (1) (2)	TiN (0.1)	-
	39	D	TiN (0.1)	1-TiCN (3)	TiCO (0.1)	Al_2O_3 (1) (10)	TiN (0.1)	-
	40	E	TiN (0.1)	1-TiCN (0.5)	TiO_2 (0.1)	Al_2O_3 (1) (2.5)	-	-

Table 21

Insert		Thickness of Al_2O_3 Layer (μm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
This Invention	41	11.1	13.3	10.3	0.29	0.30
	42	9.0	11.1	8.6	0.22	0.27
	43	7.1	9.0	6.8	0.24	0.21
	44	5.0	6.0	5.0	0.24	0.24
	45	3.0	3.3	2.9	0.27	0.27
	46	3.0	3.5	2.8	0.30	0.29
	47	6.2	7.7	5.9	0.28	0.25
	48	6.2	7.5	6.0	0.22	0.31
	49	6.0	8.2	5.9	0.24	0.24
	50	7.9	9.3	7.5	0.19	0.27
	51	8.0	10.0	7.7	0.17	0.22
	52	2.0	2.1	2.0	0.27	0.19
	53	2.0	2.2	2.0	0.27	0.16
	54	10.3	12.8	9.4	0.17	0.19

Table 22

Insert		Thickness of Al_2O_3 Layer (μm)			Flank Wear (mm)	
		Flank	Edge	Rake	Continuous Cutting	Interrupted Cutting
This Invention	55	10.1	12.4	9.6	0.18	0.19
	56	2.4	3.3	2.2	-	0.26
	57	2.5	3.0	2.2	-	0.21
Conventional	31	10.5	18.7	5.0	0.20	Failure at 2.5 minutes
	32	7.1	12.0	3.1	0.20	Failure at 2.5 minutes
	33	4.8	7.9	2.4	0.21	Failure at 3.5 minutes
	34	3.0	5.4	1.4	0.21	Failure at 3.0 minutes
	35	5.9	10.8	3.0	0.21	Failure at 1.5 minutes
	36	6.1	11.3	3.2	0.22	Failure at 2.0 minutes
	37	7.9	13.8	3.3	0.23	Failure at 4.0 minutes
	38	2.0	4.0	0.9	0.21	Failure at 4.5 minutes
	39	9.6	17.0	4.4	0.23	Failure at 3.5 minutes
	40	2.5	4.4	1.2	-	Failure at 2.5 minutes
Remark: Failure is caused by chipping.						

Claims

1. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate and hard coating layers including an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers having an average thickness of 3 to 20 μm and being formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
said aluminum oxide-based layer containing 0.005 to 0.5 percent by weight of chlorine.

2. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate hard coating layers wherein said hard coating layers comprise at least one layer selected from the group consisting of a titanium carbide layer, a titanium nitride layer, a titanium carbonitride layer, a titanium oxide layer, a titanium carboxide layer, a titanium nitroxide layer and a titanium carbonitroxide layer, and an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers have an average thickness of 3 to 20 μm, and are formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
wherein said aluminum oxide-based layer contains 0.005 to 0.5 percent by weight of chlorine.

3. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate and hard coating layers including an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers having an average thickness of 3 to 20 μm and being formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
said aluminum oxide-based layer containing 1.5 to 15 percent by weight of titanium and 0.005 to 0.5 percent by weight of chlorine.

4. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate hard coating layers wherein said hard coating layers comprise at least one layer selected from the group consisting of a titanium carbide layer, a titanium nitride layer, a titanium carbonitride layer, a titanium oxide layer, a titanium carboxide layer, a titanium nitroxide layer and a titanium carbonitroxide layer, and an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers have an average thickness of 3 to 20 μm, and are formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
wherein said aluminum oxide-based layer contains 1.5 to 15 percent by weight of titanium and 0.005 to 0.5 percent by weight of chlorine.

5. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate and hard coating layers including an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers having an average thickness of 3 to 20 μm and being formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
said aluminum oxide-based layer containing 0.5 to 10 percent by weight of zirconium and/or hafnium and 0.005 to 0.5 percent by weight of chlorine.

6. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate hard coating layers wherein said hard coating layers comprise at least one layer selected from the group consisting of a titanium carbide layer, a titanium nitride layer, a titanium carbonitride layer, a titanium oxide layer, a titanium carboxide layer, a titanium nitroxide layer and a titanium carbonitroxide layer, and an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers have an average thickness of 3 to 20 μm, and are formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
wherein said aluminum oxide-based layer contains 0.5 to 10 percent by weight of zirconium and/or hafnium and 0.005 to 0.5 percent by weight of chlorine.

7. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate and hard coating layers including an aluminum oxide-based layer essentially consisting of aluminum oxide, said hard coating layers having an average thickness of 3 to 20 μm and being formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;
said aluminum oxide-based layer containing 1.5 to 15 percent by weight of titanium, 0.005 to 0.5 percent by weight of chlorine and 0.5 to 10 percent by weight of zirconium and/or hafnium.

8. A coated carbide alloy cutting member exhibiting excellent resistance against chipping comprising: a tungsten carbide substrate hard coating layers wherein said hard coating layers comprise at least one layer selected from the group consisting of a titanium carbide layer, a titanium nitride layer, a titanium carbonitride layer, a titanium oxide layer, a titanium carboxide layer, a titanium nitroxide layer and a titanium carbonitroxide layer, and an aluminum

oxide-based layer essentially consisting of aluminum oxide, said hard coating layers have an average thickness of 3 to 20 μm, and are formed on said tungsten carbide substrate by chemical and/or physical vapor deposition;

wherein said aluminum oxide-based layer contains 1.5 to 15 percent by weight of titanium, 0.005 to 0.5 percent by weight of chlorine and 0.5 to 10 percent by weight of zirconium and/or hafnium.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 10 0088

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	WO 92 17623 A (KRUPP WIDIA GMBH) 15 October 1992 * claims 1,4 *	1-8	C23C16/40 B23B27/14
A	US 4 112 148 A (FONZI FRANK) 5 September 1978 * column 5, line 1 - line 36 *	1-8	
A	PLASMA CHEMISTRY AND PLASMA PROCESSING, vol. 12, no. 2, 1 June 1992, pages 129-145, XP000266311 PATSCHEIDER J ET AL: "PLASMA-INDUCED DEPOSITION OF THIN FILMS OF ALUMINUM OXIDE" * paragraph 3.1 *	1-8	
A	FR 2 393 852 A (SANDVIK AB) 5 January 1979 * examples 1-4 *	1-8	
A	BERICHTE DER DEUTSCHEN KERAMISCHEN GESELLSCHAFT, MARCH 1972, WEST GERMANY, vol. 49, no. 3, ISSN 0365-9542, pages 76-80, XP000671483 SCHACHNER H ET AL: "Chemical vapour deposition of aluminium oxide layers on aluminium by hydrolysis of aluminium chloride" * page 79, left-hand column *	1-8	TECHNICAL FIELDS SEARCHED (Int.Cl.6) C23C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 April 1997	Ekhult, H

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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